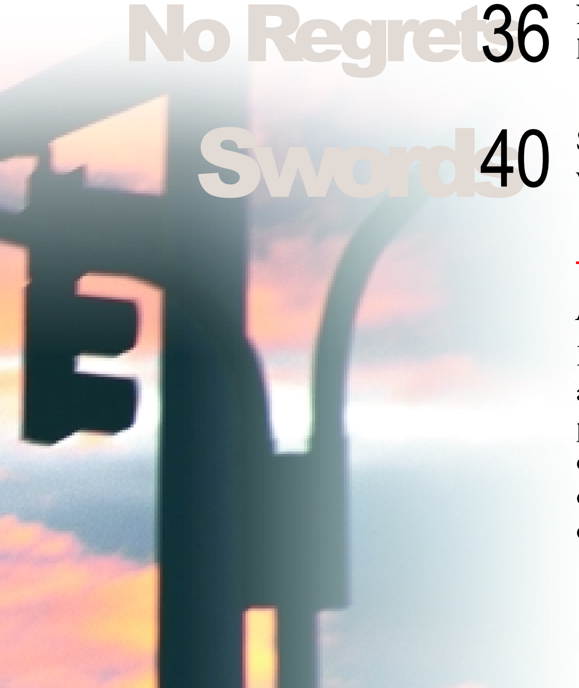
Contents



About the Cover:

Family vehicles in the U.S. consume enough fuel each year to cover a regulation-size football field to a depth of about 40 miles. FETC partners with industry and other organizations to develop and deploy ultra-clean, high-performance fuels, ensuring that we can continue to depend on our transportation-based economy to bolster our transportation-based lifestyle.

Charles A. Komar
Product Manager, Natural Gas Supply and Storage

Office of Product Management for Fuels and Specialty Markets

Where's the Gas

Natural Gas, That Is

The date? 1821. The event? The birth of the U.S. natural gas industry. William Hart, considered America's "father of natural gas," dug a 27-foot deep natural-gas well in Fredonia, New York. The well was covered with a large barrel, and the gas was conveyed through wood pipes to nearby homes.

Today, about 11,000 natural gas wells are drilled each year to an average depth of about 5,100 feet (and twice that for offshore wells), but drilling to depths of 30,000 feet or more is not uncommon. And about 300,000 natural gas wells, 125 natural gas pipeline companies, and more than 1,200 gas distribution companies deliver natural gas to customers in all 50 states.

This huge infrastructure delivers a huge volume of gas to U.S. customers, but we need more. We need to site more wells and produce more gas from new and existing wells. Why? The current annual demand for natural gas in the U.S. is about 22-24 trillion cubic feet (Tcf). The Energy Information Administration (EIA) predicts an annual demand of 30-35 Tcf by 2020.

Natural gas consumption is expected to rise in all sectors, but consumption in the industrial sector—specifically for electric power generation—is expected to grow the most rapidly and to be the principal driver for the predicted huge increase in total annual demand. Today, over 70 percent of the total electric generating capacity in the U.S.—or 575 gigawatts (GW)—is based on fossil-fuel power generation. The EIA predicts that over 400 GW of new capacity will be built by 2020, and that 85 percent of this new capacity will be natural-gas-based power systems.

Why? Natural gas is the cleanest of the fossil fuels. We have an excellent natural gas transmission and distribution infrastructure.

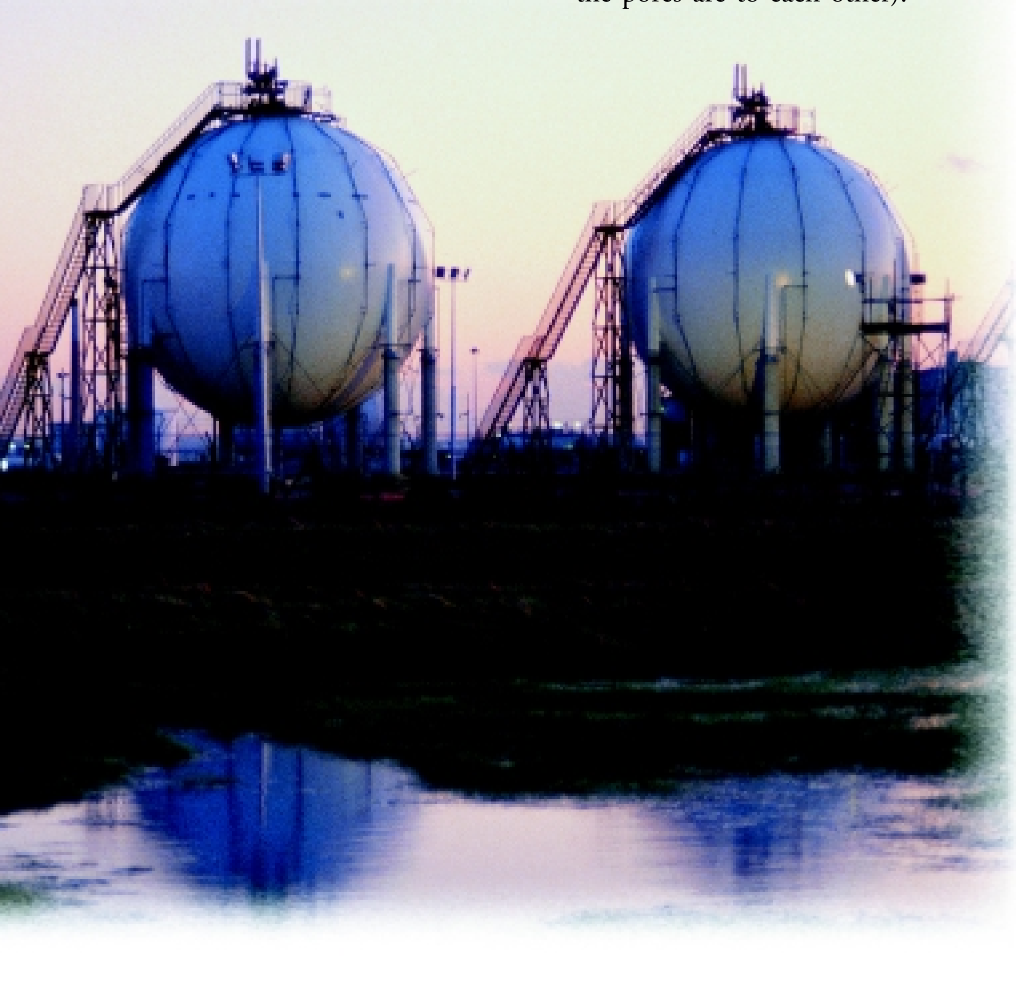
Natural gas is stored to meet seasonal needs and short-term peaks in demand. In addition to underground gas storage, distribution companies operate aboveground facilities. Aboveground storage tanks provide supplemental gas for limited periods, about 5 to 15 days of peak demand.

And deregulation of the electric industry strongly favors natural gas. Natural gas is the preeminent fuel for distributed generation systems—where electric power generation is at or near the end-user's site—because of its widespread availability and the convenience of delivery.

What is Natural Gas and Where is it?

Natural gas is a naturally formed, colorless, odorless, and combustible fuel that exists as a gas or vapor at ordinary temperatures and pressures. It is almost entirely composed of methane (the simplest hydrocarbon or carbon-hydrogen molecule, CH_4), but also contains small amounts of other hydrocarbons, such as ethane (C_2H_6), and propane (C_3H_8). A tiny amount of the odorant mercaptan (which is non-hazardous at very low levels) is added to the natural gas that comes into your house—to give it a distinct unpleasant odor that makes it detectable. Natural gas is one of the cleanest-burning fuels available today.

Natural gas is found underground in layers of sedimentary rock that is porous and permeable. *Sedimentary rock* is consolidated loose sediment, including plant and animal remains, that has been deposited on an ocean floor. Layers of sediment continue to accumulate and over time, are subjected to great pressure, which increases the temperature and squeezes and solidifies the sediment into hard rock. *Porosity* is the percentage of a rock that is occupied by spaces between the individual grains of the rock (like a sponge), and *permeability* is a measure of how easy it is for fluids to flow through the rock (how connected the pores are to each other).

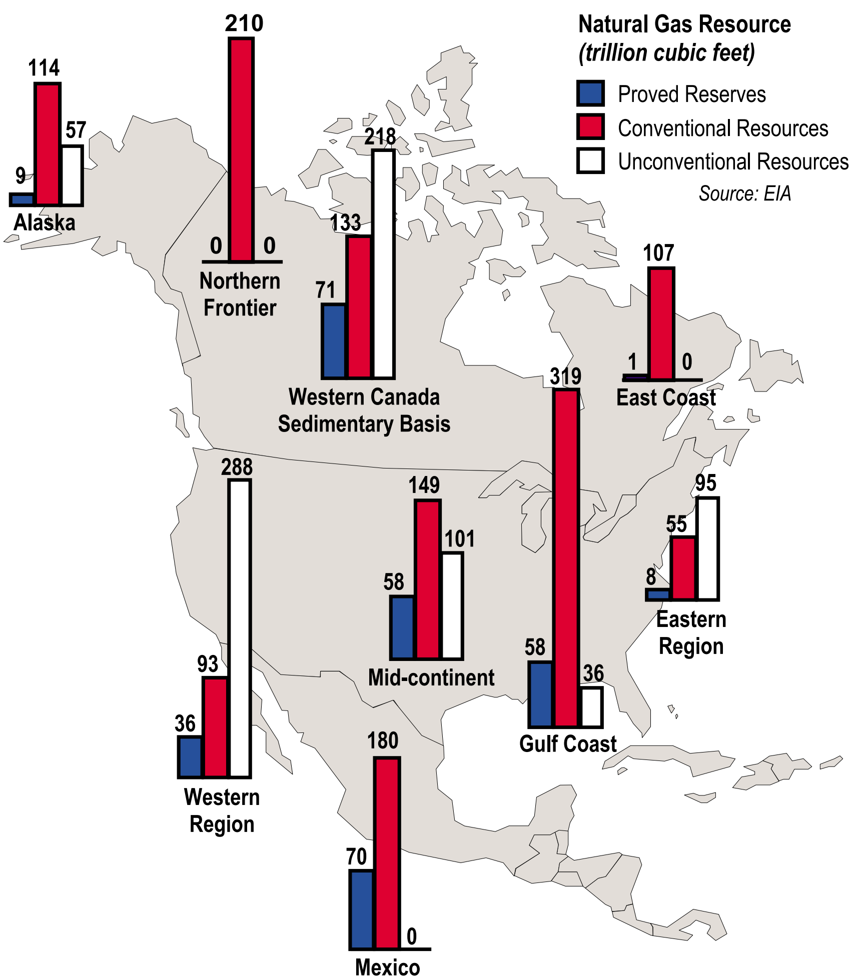


Natural gas is located in reservoirs. A *reservoir* is a given subsurface volume of rock known to contain natural gas. The reservoir rock is overlain by an impervious rock that acts like a lid, keeping the gas from flowing out of the reservoir to the surface. A *conventional* reservoir contains a discrete well-defined accumulation of gas, and standard production technology is used to recover the gas. Conventional reservoirs include those that are partially depleted—some or most of the gas has already been extracted.

Unconventional reservoirs include *coalbed methane*—the gas associated with layers of coal which can be problem in mining coal, *tight gas sands*—gas trapped in layers of relatively impermeable sandstone, and *deep gas*—gas found in sedimentary basins at depths greater than 15,000 feet below the surface. (See "Coalbed Methane Gas: From 'Miner's Curse' to Valuable Resource" in the September 1998 issue of *FETC Focus*.) *Gas hydrates* is a potential, huge, unconventional gas resource. (See "Hydrates—The Final Natural Gas Frontier" on page 9, and "Hydrates: Fire From Ice" in the September 1998 issue of *FETC Focus*.)

Natural gas *reserves* are the identified deposits from which natural gas can be extracted profitably at current prices and using present technology. *Emerging* reserves (also called *reserve growth*) are the volumes expected to be added to reserves through

Distribution of North America's Natural Gas Resource



revisions to reserve estimates, addition of new reservoirs, and application of new recovery techniques. The natural gas *resource* is the total volume of natural gas on Earth that has not yet been extracted—the sum of all reserves plus all other deposits that may eventually become available, including those presently unknown (hypothetical) or presently unrecoverable.

FETC is actively involved in projects to assess the total resource, locate the reserves, and economically drill and produce the natural gas.

How Much Gas Is There?

In 1972, M. King Hubbert reported to the U.S. Congress that natural gas production would peak at 23 Tcf per year in 1977, and then would decline dramatically to levels of roughly 10 Tcf by 1996. This dire prediction was based on a constrained and firmly limited natural gas resource of approximately 1,000 Tcf.

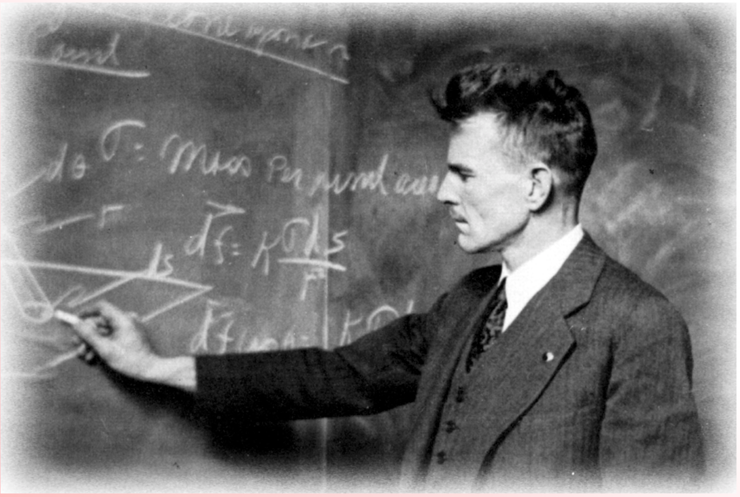
Later advances in technology provided gas from unexpected and prolific sources—sources that to Hubbert, were perhaps even more speculative than the gas hydrates resource is to us today. In recent years, pessimism regarding future natural gas supplies has begun to re-emerge, and analysts are predicting that gas production will peak between 2010 and 2020 and will then decline, once again constrained by a finite gas resource.

But, how large this resource is remains to be defined. In fact, we have not yet sufficiently characterized emerging and hypothetical natural gas sources to give us a definitive answer on the size of the resource. The U.S. Geological Survey, the Gas Research Institute, and the National Petroleum Council as well as independent experts collectively place the total U.S. potential natural gas resource, excluding hydrates, at about 1,580 Tcf. This is sufficient gas to meet U.S. demand at current levels for about 65 years: at the predicted annual consumption level of 30 to 35 Tcf by 2020, we have enough gas to supply U.S. demand until about 2050.

Geologists are now referring to estimates of the natural gas resource as “forecasts” rather than assessments. Resource forecasts, like those for weather, are updated and progressively adjusted as more information becomes available. For example, deep gas reservoirs in the U.S. could be much larger than the currently estimated volume. And the U.S. hydrates resource alone has been forecast to be a mammoth 320,000 Tcf. If even a portion of this potential proves to be real or producible, the U.S. is not in danger of running out of natural gas for a long, long time.

One of FETC’s goals is to forecast and characterize the total natural gas resource, including deep gas and coalbed methane. In the early 1980s, FETC performed

M. King Hubbert's Predictions



Courtesy of the Society of Exploration Geophysicists

M. King Hubbert would not have predicted that U.S. natural gas production would peak in 1972 and decline rapidly by 1996 had he known how much technology would advance—enhancing production from known reservoirs and leading to discoveries of additional reservoirs.

Geophysicist Dr. M. (Marion) King Hubbert, 1903-1989, was a world authority on the estimation of energy resources and on the prediction of their patterns of discovery and depletion. His research in structural geology, the mechanics of earth deformation, and the physics of underground movement of fluids led to sweeping changes in oil and gas exploration and production.

He was scoffed at for his prediction in 1956, when he was working for Shell Oil Company, that U.S. oil production would peak about 1970 and would then decline. This prediction was based on his famous Hubbert Curve, a mathematically derived bell-shaped curve on ultimate cumulative production in the lower 48 states. His prediction turned out to be remarkably accurate.

Estimates of the technically recoverable gas resource in the U.S. are about double the estimates of the mid 1970s. This huge increase is a major FETC success—our research and development efforts have led to discovery of new fields and better estimating techniques, as well as new and improved technologies for gas recovery.
Charles A. Komar, FETC Product Manager, Natural Gas Supply and Storage

some of the earliest research on characterizing methane hydrates, and is now involved in a second wave of methane hydrate research. The result of this research could be a vastly enlarged natural gas resource.

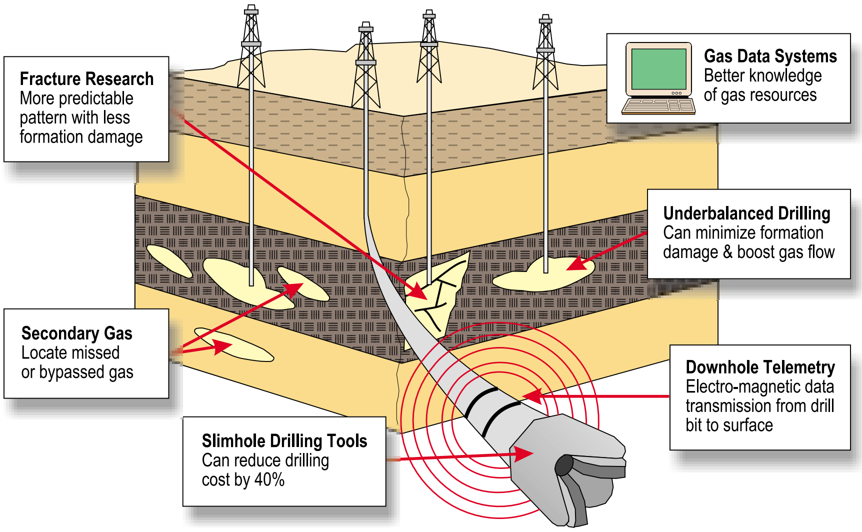
Finding New Sources of Gas

It's difficult to find natural gas from the surface of Earth—when it's located underground at varying depths in reservoirs of varying size and with varying characteristics. Precisely locating newly discovered reservoirs and forecasting the volume of gas available in these and in existing reservoirs depend on their detailed characterization.

FETC is involved in developing strategies that will expand the U.S. natural gas reserves. Our projects in *natural gas supply* will help ensure that future gas supplies can be estimated with confidence. The research includes *resource and reserve assessments*—characterizing the geology, gas availability, and specific reservoir geometry, and then fostering the development of products that will facilitate extraction from these reservoirs.

Continuing improvements in *diagnostics technology* (using seismic waves to determine subsurface geology and reservoir characteristics) are making it easier to site productive wells. But even when a reservoir has been located and characterized, it's extremely difficult to precisely locate wells to tap the maximum volume of gas with minimum difficulty and at minimum expense.

Natural Gas in the 21st Century: How We Can Get It



Developing Technology for Gas Recovery

Drilling a well is the moment of truth for the exploration geologist, and is the most expensive part of natural gas extraction, accounting for 30 to 35 percent of the total production process. A well is a hole, called a "borehole" or "wellbore," that goes through the rock layers, creating a difference in pressure—reduced pressure in the wellbore versus higher pressure in the surrounding rock. This causes gas to flow through the rock towards the lower pressure in the wellbore and provides a path for the gas to escape the reservoir.

Drilling fluid is forced down the hollow center of the drill pipe to lubricate and cool the drill bit. The drilling fluid flows back to the surface through the space between the drill pipe and the borehole, carrying the cuttings of rock up from the bottom, and maintaining hydrostatic pressure.

FETC is involved in developing production concepts for gas recovery from emerging reserves and in *drilling, completion, and stimulation technologies*—developing new and improved technologies to increase production from existing fields and to increase the value of producing wells.

This research includes development of *underbalanced drilling fluids* that reduce the pressure in the wellbore to below the pressure within the reservoir rock. The fluids include hollow glass beads as an additive to maintain the wellbore cleaning capacity of the fluids, yet lower their weight and reduce their influx into the producing reservoir. (Pressure in a wellbore is usually maintained at or slightly above the reservoir pressure.)

FETC recently announced the selection of four companies and a university to pioneer the *next generation* in natural gas drilling technologies. The awards are for one year but can be extended to two more years for field testing of the concepts. Next generation means advanced, faster, and more efficient drilling techniques and technologies, such as higher performance cutters that won't shatter in higher temperature drilling, drilling with hydraulic pressure pulses, and an integrated, steerable drilling system that is cheaper than current drilling practices.

Production from unconventional reservoirs can be enhanced by improving the effectiveness of drilling systems, increasing the rate at which they can bore into more difficult formations while reducing costs. The deeper, harder rock formations that comprise much of the unconventional gas reserves in the U.S. require unique drilling strategies.

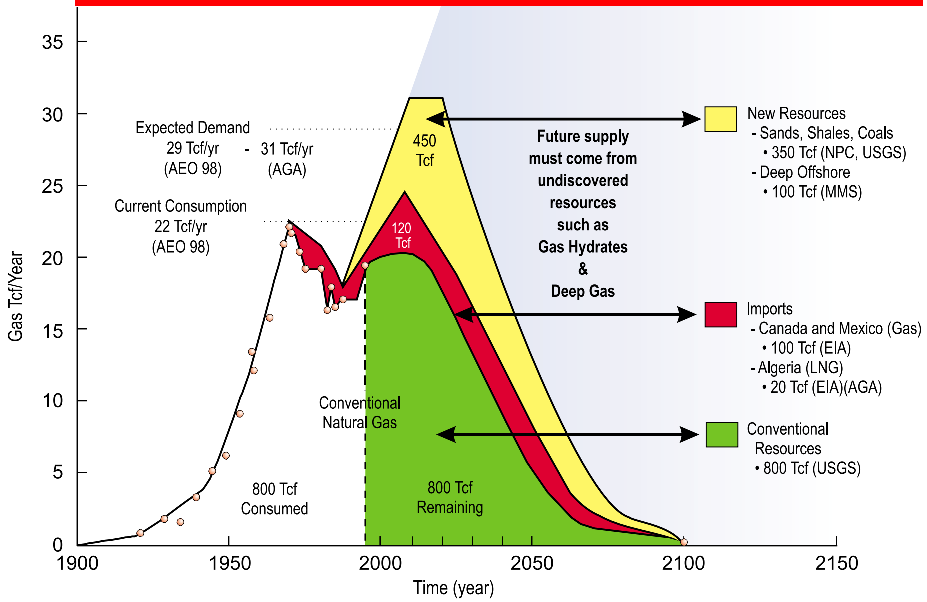
Increasing Recovery Efficiency

When gas flows very slowly through rock formations over long periods of time, these wells usually produce at uneconomically low rates. These low-permeability or tight formations (e.g., tight gas sands) pose a special challenge to the producer. Natural gas is trapped in these rocks, but it's extremely difficult to extract—except where there are natural fractures or cracks, which act as channels or pathways for the gas. If the rock formation has a dense network of fractures and if the wellbore intersects enough of these natural fractures, economic production results.

The presence of natural fractures in the rock is the single most important aspect in locating successful wells in tight formations. Horizontal or slant wells increase the chances of intersecting natural fractures and increase the nearby drainage area of the well. Although these wells are more expensive to drill than vertical wells, the higher production can offset the added cost.

FETC is working with industry on ways to reduce drilling costs for directional drilling and to

New Resources Need to be Developed



ensure intersecting the natural fractures. Projects include development of a *steerable air percussion drilling system*—which yields high penetration rates while directionally drilling in hard rock, an *advanced mud hammer*—which increases penetration rates in medium-to-hard formations, and advanced techniques for use in *slimhole drilling*. Slimhole drilling (small-bore drilling) can serve as a lower cost alternative to drilling of exploratory gas wells and can increase the productivity of existing wells—deepening existing holes to stratigraphically lower production zones, or as added laterals from existing wells to intersect natural fracture systems. The use of slimhole wells has led to a 75 percent reduction in the amount of surface disturbed and in the amount of waste generated, minimizing the environmental impact of drilling activities.

If a rock formation lacks natural fractures, drillers create them by stimulating or fracturing the well. A fracturing fluid, usually water with additives, is forced down the wellbore under sufficient pressure to extend or expand the fractures in the desired producing zone. The expanded fractures can be propped open by including a brace or support (*proppant*), such as sand grains, in the fracturing fluid.

FETC has a cost-sharing program in place to continue testing a stimulation technology known as liquid carbon dioxide (CO_2)/sand fracturing in the U.S. The method has been used in Canada for some time, and has been successfully tested in several U.S. reservoirs. Sand is the proppant and liquid CO_2 is the fracturing fluid. The liquid CO_2 converts back to gaseous CO_2 at reservoir temperatures and exits the formation, leaving behind the sand proppant in the induced fractures in the rock.

The stimulation method was compared with two other stimulation techniques in 15 tight-gas wells in eastern Kentucky. Wells stimulated with liquid CO_2/sand produced nearly twice as much natural gas as those treated with straight nitrogen, and about four times as much gas as those stimulated with nitrogen/foam. Liquid CO_2/sand fracturing treatments are more expensive than conventional stimulation techniques, but the shorter cleanup time and the lack of well damage mean the wells are productive sooner and stay productive longer.

Natural Gas is the Fuel of the 21st Century

Natural gas is a nearly ideal fuel for the U.S. as we cross the millennium and face new challenges and opportunities for powering the economy while protecting our environment. Improved technology is leading the way to cleaner, more efficient uses of gas and in finding cost-effective ways to produce it from lower quality reserves. And FETC is working in partnership with private industry to accomplish this technology development.

FETC Point of Contact:

Charles A. Komar
Product Manager
Natural Gas Supply and Storage
Office of Product Management for Fuels and Specialty Markets
Phone: 304/285-4107
E-mail: ckomar@fetc.doe.gov

Albert B. Yost II
Director, Fuels Resources Division
Office of Project Management
Phone: 304/285-4479
E-mail: ayost@fetc.doe.gov